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BEACH FILL AND SEDIMENT TRAP AT CAROLINA BEACH, NORTH CAROLINA

by

J. Thomas Jarrett

DEPARTMENT OF THE ARMY
US Army Engineer District, Wilmington
PO Box 1890, Wilmington, North Carolina 28042-1890

and

J. Michael Hemsley

Coastal Engineering Research Center

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39180-0631

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The beach fill and inlet sediment trap at Carolina Beach, North Carolina, were monitored under the Monitoring Completed Coastal Projects Program. The objectives of the effort were the determination of the adequacy of the trap to serve as a primary source of beach nourishment material for the project and to assess the impact of the trap on the inlet's ebb tide channel and delta. Considerable hydrographic and oceanographic data were collected and evaluated. Results of the monitoring program provided a critique of the project's performance as well as guidance on the use of sediment traps in inlets.

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PREFACE

This report was prepared by the US Army Engineer Waterways Experiment Station (WES), through the Monitoring Completed Coastal Projects Program, an Operations and Maintenance program of the Headquarters, US Army Corps of Engineers (HQUSACE). The HQUSACE Technical Monitor was Mr. John H. Lockhart, Jr.

The study was conducted by personnel of the US Army Engineer District, Wilmington (SAW), and WES's Coastal Engineering Research Center (CERC), under the general direction of Dr. J. R. Houston and Mr. C. C. Calhoun, Jr., Chief and Assistant Chief, respectively, CERC; Dr. Frederick E. Camfield, Acting Chief, Dr. William L. Wood, and Mr. Thomas W. Richardson, successive Chiefs of the Engineering Development Division; and Dr. Dennis R. Smith, Chief of the Prototype Measurement and Analysis Branch. At SAW, general direction of the effort was provided by Mr. Jim Vithalane, Chief of the Engineering Division, and Mr. Limberios Vallianos, Chief of the Coastal Engineering Branch. The field data collection effort was planned by Mr. J. Michael Hemsley, Research Hydraulic Engineer, CERC, and Mr. J. Thomas Jarrett, Project Engineer, SAW. Assisting in data collection were Messrs. Michael J. Wutkowski, J. William Forman, Jeffrey A. Gebert, and Ronald Fascher, all engineers at SAW. This report was prepared by Messrs. Jarrett and Hemsley.

Commander and Director of WES during the preparation and publication of this report was COL Dwayne G. Lee, CE. Technical Director was Dr. Robert W. Whalin. District Engineer at SAW was COL Wayne A. Hanson.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
cubic yards	0.7645549	cubic metres
feet	0.3048	metres
inches	2.54	centimetres
miles (US statute)	1.609347	kilometres
square feet	0.09290304	square metres
yards	0.9144	metres

BEACH FILL AND SEDIMENT TRAP AT CAROLINA BEACH, NORTH CAROLINA

PART I: INTRODUCTION

Project History

1. Carolina Beach, North Carolina, is located approximately 15 miles* south-southeast of Wilmington, North Carolina, on a peninsula which separates the lower Cape Fear River Estuary from the Atlantic Ocean as shown in Figure 1. During October 1962, Congress authorized the construction of a beach erosion control-hurricane wave protection project along approximately 26,000 ft of ocean shoreline beginning at the northern town limits of Carolina Beach and extending south to the southern town limits of Kure Beach. In April 1965, 14,000 lineal feet of the project, lying within the town limits of Carolina Beach, were constructed while the southern segment of the authorized project was placed in a deferred category due to the inability of local interests to finance their part of the project's cost. The authorized project consisted of a beach fill placed in the form of a 25-ft-wide dune with a crest elevation of 13.5** fronted by a 50-ft-wide storm berm at el 10.5 as shown in Figure 2. This report documents and evaluates the performance of the Carolina Beach project and describes in detail the results of a monitoring program conducted between April 1981 and September 1984 under the auspices of the Corps of Engineers' Monitoring Completed Coastal Projects (MCCP) Program.

2. Carolina Beach began to experience problems along its shoreline in the early 1950's partly due to the passage of severe hurricanes over the area but, more importantly, as a direct result of the artificial opening of Carolina Beach Inlet. On 15 October 1954, Hurricane Hazel affected the entire southeastern section of North Carolina and produced the maximum observed water level at Carolina Beach of el +11.2. During Hurricane Hazel, Carolina Beach, which has natural ground elevations ranging from a maximum of el +10 along the oceanfront to el +4 along the sound shore, was completely inundated by the

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

** All elevations (el) cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

storm surge and overwashed by the large storm-generated ocean waves. Hurricane Hazel caused millions of dollars in property damage at Carolina Beach, particularly along the first several rows of oceanfront development. In addition, the storm wiped out the frontal dune and caused considerable erosion of the foreshore. Efforts to recover from Hurricane Hazel were initiated in early 1955 with the construction of a small dune and the placement of 252,000 cu yd of beach fill along the ocean shoreline.

3. Between August and September 1955, Carolina Beach was affected by three more hurricanes, Connie (12 August), Diane (17 August), and Ione (19 September), which caused additional structural damage and beach erosion. Ocean still-water levels produced by Connie, Diane, and Ione were 8.5, 6.6, and 5.7 ft, respectively. As a result of the additional ocean shoreline damage caused by these three storms, 200,000 cu yd of beach fill were placed on Carolina Beach in the fall of 1956. Also in 1956, the town of Carolina Beach constructed 12 groins along its shoreline at 1,000- to 1,200-ft intervals. The groins, which were constructed with broken concrete and natural stone, were low and rather short and terminated in water depths ranging from -2 to -4 ft.

4. Carolina Beach Inlet, located approximately 7,000 ft north of the town limits of Carolina Beach, was artificially opened by local interests in September 1952. Immediately following the opening of the inlet, an inordinately high rate of erosion began to occur along the shoreline immediately south of the inlet, and eventually progressed southward into the town limits of Carolina Beach. Between 1952 and 1963, for example, the south shoulder of Carolina Beach Inlet eroded 1,135 ft while the shoreline at the north town limits lost 293 ft. For comparison, those same general areas eroded 33 and 1 ft, respectively, during the period from 1938 to 1949. By 1963, shoreline erosion was accelerating at a point 4,000 ft south of the northern town limits. The difference in the extent of the erosion near the inlet and within the town limits resulted in a change of alignment of this section of the shoreline (Figure 3).

5. Erosion and reorientation of the shoreline south of the inlet were the direct result of the entrapment of littoral material in the ebb- and flood-tidal deltas of the new inlet. With the predominant direction of littoral transport in the area being southerly, the shoreline south of Carolina Beach Inlet became starved of littoral material, particularly during the for-

mative years of inlet delta development. As the shoreline adjacent to the inlet eroded, successive shoreline sections south of the inlet retreated to an alignment approximately parallel with the predominant approach of wave crests from the northeast. Once one section of the shoreline attained this new alignment, sediment transport from that section to the adjacent downdrift stretch decreased and caused the adjacent segment to undergo an alignment change as well. Thus, through this process of progressive erosion and reorientation, the inlet-induced shoreline erosion moved into the northern portion of Carolina Beach by the time the first stage of construction of the hurricane and shore protection project was completed.

6. The initial stage of construction of the authorized hurricane wave-shore protection project was completed in April 1965 with the placement of 2,632,000 cu yd of borrow material obtained from the Carolina Beach Harbor area. Immediately following the initial placement, considerable erosion occurred along the entire length of the fill. Over the southern 10,000 ft of the project (sta 0+00 to 100+00), the erosion was caused by hydraulic sorting of the borrow material by waves and the movement of the borrow material down slope to deeper portions of the active beach profile. These initial sorting and slope adjustments continued until 1967 when the southern 10,000 ft became fairly stable. By the time stability was reached along this 10,000-ft segment, the cross section of the fill was somewhat less than the authorized section.

7. Erosion along the northern 4,000 ft of the project (sta 100+00 to 140+00) was considerably greater than could be explained by hydraulic sorting and slope adjustments. Within the first year following initial fill placement, essentially all of the fill material was eroded from this northern section. Accordingly, authority was granted to proceed with emergency measures involving additional beach nourishment and the construction of a temporary timber groin at the northern terminus of the project. A special investigation of the erosion problem was also authorized to determine the cause of the inordinate erosion and to recommend a feasible long-term solution.

8. Emergency corrective measures were completed in March 1967 with the construction of a timber groin and the placement of 411,000 cu yd of fill. The emergency fill was completely eroded, and the temporary groin was rapidly deteriorating within a year. Continuation of severe erosion necessitated additional emergency action involving the construction of a 2,050-ft-long

rubble-mound seawall extending southward from the north end of the project, and placement of an additional 346,000 cu yd of fill. The seawall was constructed in two stages, with the first stage along with placement of the fill, completed in December 1970. The second stage of seawall construction was completed in September 1973.

9. During the period between the two stages of seawall construction, 760,000 cu yd of fill was placed along the seawall's entire length to restore the project to its authorized dimensions. Placement of this fill was completed in May 1971.

10. The special investigation of the erosion problem at the north end of the project was completed in 1970 with the results contained in a report by Jarrett (1976).* This study and a subsequent study of the feasibility of improving navigation through Carolina Beach Inlet (O'Brien 1931)** identified the entrapment of littoral sediment in the inlet as the cause of the erosion problem. The long-term solution recommended in the Carolina Beach Inlet report involved bypassing 480,000 cu yd of sand every 3 years from a sediment trap located in the throat of the inlet. This sand would be distributed along the northern end of the fill and would serve as a source of sediment for the beach to the south. The reports concluded that failure to accomplish the sand bypassing on a regular basis would result in the continued deterioration of the entire project.

11. Between the 1971 nourishment and April 1980, no additional fill material was placed on the project shoreline. As a result, severe erosion migrated to the south, as predicted, leaving only the southernmost 2,000 ft of the project showing any degree of stability.

12. In December 1980, the southeastern coastal area of North Carolina was struck by two severe storms, further aggravating erosion at Carolina Beach, particularly along the section of the project located just south of the rubble seawall. In this area, seven cottages were undermined and had to be condemned. Further south, the shoreline retreated to within 25 ft of 122 other structures, making them vulnerable to damage by another moderate storm. In

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* J. T. Jarrett. 1976 (Feb). "Tidal Prism - Inlet Area Relationships," GITI Report 3, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

** M. P. O'Brien. 1931. "Estuary Tidal Prisms Related to Entrance Areas," Civil Engineering, Vol 1, No. 8, pp 738-739.

response to the cumulative effects of the inlet-related and storm-induced to provide protection against moderate storms until the entire project could be restored to authorized dimensions.

13. Material for the emergency fill was obtained from a borrow area located in Carolina Beach Inlet. This borrow area, shown in Figure 4, began at the Atlantic Intracoastal Waterway (AIWW) and extended approximately 2,000 ft seaward. Removal of material from this section of the inlet effectively created a sediment trap which could supply material for future beach nourishment operations in accordance with the long-term erosion control plan for Carolina Beach. The performance of the sediment trap is discussed later in this report.

14. Construction of the Carolina Beach project was completed in July 1982, following the placement of 3,662,000 cu yd of sand along the entire length of the project. The borrow source used for the final phase of construction was an upland area located along the east bank of the Cape Fear River south of the Carolina Beach Sewage Treatment Plant (Figure 3). This final phase of construction completely restored the berm and dune section up to the southern end of the rubble-mound seawall, baseline sta 116+40, and provided a beach berm at el +6.5 in front of the seawall. The design volume for the final phase of project construction was determined by assuming that the restored beach profile would parallel the existing profile out to a depth of closure of approximately -25 to -28 ft as shown in Figure 5. Because the upper portion of the fill had been designed and authorized, enough material was placed to allow for a reasonable amount of overfill and resulted in the designed seaward projection of the shoreline at mean high water. Since controlled placement of fill below the normal level of wave activity is not possible, the design volume of material was distributed along the project shoreline in the form of a construction berm (Figure 5). The redistribution of the construction berm material to the deeper portion of the active profile was to be accomplished by normal wave activity.

Monitoring Completed Coastal Projects Program

15. This beach erosion control-hurricane protection project was among the first four projects selected for monitoring in 1981 under the then new MCCP Program. The program has as its goal the advancement of coastal

engineering technology. It is designed to determine how well projects are accomplishing their purposes and resisting the attacks of the physical environment. These determinations, combined with concepts and understanding already available, will lead to upgrading the credibility of predictions of cost effectiveness of engineering solutions to coastal problems; to strengthening and improving design criteria and methodology; to improving construction practices; and to improving operation and maintenance techniques. Additionally, the monitoring program will identify concerns that laboratories should address more intently. Stated in another way, the objective is the advancement of the engineering science derived from insights into the physics that laboratory studies have developed.

16. To develop the direction for the MCCP Program, the Corps established an ad hoc committee of coastal engineers and scientists. The committee formulated the program's objectives, developed its operational philosophy, recommended funding levels, and established criteria and procedures for project selection. A significant result of their efforts was a prioritized listing of problem areas to be addressed, essentially a listing of the program's areas of interest (Table 1). The initial list complied had only 20 items. As the program has grown, so has the list; the final three items were recently added.

17. The selection process envisioned by the committee members has worked well since the first projects were nominated in 1981. Periodically, the Corps' coastal offices are invited to nominate projects for monitoring under the program. Nominations are reviewed and prioritized by a selection committee comprised of representatives from the Headquarters, US Army Corps of Engineers (HQUSACE), US Army Engineer Waterways Experiment Station Coastal Engineering Research Center (CERC), and several coastal division offices. Final selection is based on the prioritized list of projects and available funding.

18. While guidance is provided by HQUSACE, management of the program rests with CERC. Operation of the program, though, is a cooperative effort between CERC and the individual Corps District offices. The development of monitoring plans and conduct of collecting data depend on the combined resources of CERC and the Districts.

PART II: MONITORING PROGRAM

Objectives

19. There were two basic objectives of the Carolina Beach monitoring program. First was a determination of the adequacy of the trap in the inlet to serve as a primary source of beach nourishment material for the project. This required measurement of the volume of material accumulating within the trap over various periods of time and the volume loss of fill from the shore protection project over corresponding periods. In addition to the volume measurements obtained through surveys, evaluation of trap performance required tide and wave data collection, analysis of accumulated sediment properties for comparison with beach sediment characteristics, and tidal flow measurements in Carolina Beach Inlet. The second objective was to assess the impact of the inlet throat trap on the inlet's ebb tide channel and delta. Relatively small traps had been dredged in the throat of Carolina Beach Inlet in 1967 and 1968 under a CERC research program to determine the impact of such a trap on the channel and delta. These traps had volume capacities of about 100,000 cu yd. Following dredging of the traps in 1967 and 1968, a channel developed through the inlet's ocean bar. A third dredging of a trap in 1970, however, failed to produce any change, and assessments of the impacts of the trap on the ocean bar were inconclusive. The larger capacity trap, approximately 400,000 cu yd, created by the 1982 emergency fill offered an excellent opportunity to reexamine the effects of a trap on the ebb tide channel and delta.

Data Collection

20. The monitoring program extended over a 42-month period from April 1981 through September 1984. The basic activities comprising the effort were hydrographic surveys of the inlet trap and ocean bar; tidal current measurements in the throat of the inlet; beach onshore and offshore profile surveys; aerial and ground photographic coverage of the beach; sediment sample collections and analyses; continuous wave and tide gaging; and daily visual observation of wave direction. The daily visual observations of wave direction were eliminated from the program. The frequencies at which various activities were to be accomplished are shown in Figure 6. The emergency beach fill placed on

Carolina Beach in April-May 1981 in response to the December 1980 storms was followed by the restoration of the entire project between December 1981 and July 1982. Beach-fill operations, combined with the initiation of ocean-bar channel dredging in Carolina Beach Inlet in September 1982, resulted in modifications in the original monitoring program schedule as set forth in Figure 6. With the initiation of dredging in Carolina Beach Inlet, one of the objectives of the monitoring program, determination of possible effects of the sediment trap in the inlet throat on the ocean bar and channel, could not be evaluated because of man-made changes to the channel. In any event, useful information did result from the overall program, particularly with respect to the operation of the sediment trap and the behavior of the beach fill. These results are discussed in Part III.

21. Overall surveys of the inlet trap, its surrounding area, and ocean bar were planned annually through 1983 when it was anticipated that the trap would be completely filled. Because the trap failed to fill, surveys were continued into 1984. These surveys provided bathymetry covering the area shown in Figure 4.

22. A predredging survey of the sediment trap was a'complished 21-22 April 1981 and was allowed by a postdredging survey compiled from surveys made between 8 and 27 May 1981. Additional surveys of the sediment trap were made on the following dates:

a. 15-16 September 1981.

b. 16 December 1981.

c. 30 August-3 September 1982.

d. 14-18 July 1983.

e. 26-27 April-1 May 1984.

23. Overall surveys of Carolina Beach Inlet extending from the AIWW to the outer edge of the ocean bar were made on the following dates:

a. 15-21 September 1981.

b. 4 April 1983.

c. 31 August 1983.

d. 26 April-2 May 1984.

Separate surveys of the inlet gorge and ocean bar channel were made 30 August-September 1982, 14-18 July 1983, and 3-11 July 1984.

24. Measurements of tidal flows through the throat of Carolina Beach Inlet were planned for before and immediately after dredging of the trap and

6, 12, and 18 months thereafter. Because a navigation channel through the ocean bar of the inlet was authorized in February 1982, tidal flow measurements were planned following channel excavation--if it was excavated during the course of the monitoring program. All of the measurements would be along a single cross section within the throat of the inlet. Current velocities and directions were planned at three to four vertical stations on the cross section, with the observations made at three to five levels between the surface and bottom at each station. Observations were to be made over a period of about 14 hr to define the flows through a tidal cycle.

25. Tidal current measurements were actually made in the throat of the inlet on 22 April 1981, prior to the dredging of the sediment trap; on 11 June 1981, following the excavation of the trap; on 20 December 1981, approximately 6 months after trap excavation; and on 8 September 1982. The monitoring schedule called for additional measurements following excavation of the ocean bar channel; however, due to the extended period of dredging in the bar channel, those measurements were not taken.

26. Beach surveys were made on a series of 28 profiles, beginning at a point on Wilmington Beach 2,000 ft south of the southern town limits of Carolina Beach (sta -20+00) and extending to Carolina Beach Inlet (sta 200+00). Onshore surveys were made at all 28 stations; combined onshore-offshore surveys were made at 15 stations. Profile stations included in the monitoring program are listed in Table 2 and shown in Figure 7.

27. The Wilmington District had performed an onshore survey of Carolina Beach between baseline sta 0+00 and 135+00 in January 1981 prior to the emergency beach fill and initiation of the monitoring program. Preemergency and postemergency fill onshore and offshore profile surveys were made by the dredging contractor during April and May 1981 between baseline sta 69+00 and 128+00. The dates, extent, and type of beach profile surveys made during the monitoring period are listed in Table 3.

28. Photographic overflights covered the shoreline from a point 2,000 ft south of the town limits of Carolina Beach to a pcint 2 miles north of Carolina Beach Inlet. Color prints were provided on a 9- by 9-in. standard format with 60 percent overlap between photographs at a scale of 1:6,000. In addition, high altitude color photographs (1:12,000 scale) was taken of Carolina Beach Inlet.

29. Aerial photographs of Carolina Beach and Carolina Beach Inlet were

obtained on 14 May 1981, 25 September 1981, 17 January 1982, 16 October 1982, and 3 March 1984. Only the 25 September 1981 photographs did not include the high altitude (1:12,000 scale) coverage of the inlet.

30. The monitoring plan included ground photography at eight profile stations within the limits of the Carolina Beach project at approximately 6-month intervals. An upcoast (north) and downcoast 8- by 10-in. black and white photograph was scheduled for each profile station, resulting in at least 16 photographs per mission.

31. Ground level photography was obtained at eight baseline stations along Carolina Beach on 25 June 1981 and 3 August 1982. Seven of the photograph stations were spaced at 2,000-ft intervals between sta 0+00 and 120+00. The eighth station was located at the Carolina Beach Fishing Pier at approximately sta 133+00. Photographs looking both north and south were taken at each station. Polaroid photographs were taken at the same general locations described above on 17 September 1984 as part of the field inspection following Hurricane Diana, which struck the area on 12-13 September.

32. Surficial sediment samples were planned with 3 samples on the inlet's ocean bar; 7 samples within the inlet throat trap; 15 samples on each of two beach profiles, approximately 3,000 ft north and south of Carolina Beach Inlet, respectively; and 15 samples on each of 3 beach profiles along the Carolina Beach shore protection project.

33. Sediment samples were collected as follows:

a. Three surficial samples from the north, middle, and south portions of the ocean bar were collected on 14 May 1981.

b. Samples from beach profile sta 30+00, 70+00, 100+00, and 130+00 were collected in August 1980 with samples being taken from the dune crest out to a depth of -20 ft.

c. Two borings were taken in the inlet throat borrow area prior to the April-May 1981 emergency beach fill; however, only one sample was within the area actually excavated. On 18 June 1981, samples of the in-place fill material from the inlet were collected at sta 75+00, 86+00, 94+00, 117+00, and 126+00. Four samples were taken at each station.

d. Samples were taken from 15 borings within the upland borrow area for the December 1981-July 1982 fill. Samples of in-place fill material were collected at eight points along Carolina Beach on 26 August 1982. Four samples were collected at each point.

e. Eleven vibracores were taken in Carolina Beach Inlet in August 1984 at the locations shown in Figure 4. A total of 70 samples were extracted from the cores for granulometric analysis. The vibracores were taken in connection with the 1985 renourishment of Carolina Beach and were not part of the monitoring program.

34. Two tide gages were installed in April 1981, one on the Center Fishing Pier, located just south of Carolina Beach, and the other at Carolina Inlet Marina, located at the confluence of Carolina Beach Inlet and the AIWW. Except for small breaks in the record and the loss of the Center Fishing Pier gage during Hurricane Diana, these gages provided continuous tide records during the monitoring period. Normal tide range at Carolina Beach is 4 ft.

35. A wave gage was planned for the Center Fishing Pier and was to be supplemented by wave direction observations made daily. Unfortunately, an observer could not be located, so the observations were not made.

36. The wave gage was installed on the pier in June 1981, and telephone hookup to the CERC Field Research Facility in Duck, North Carolina, was made on 8 August 1981. The gage operated until late February 1982 when the transducer failed. After repairs were made in mid-May, it operated for 2 months until it suffered another transducer failure. Storms during the winter of 1982-1983 and lightning in May 1983 repeatedly damaged the gage, resulting in a decision to abandon the installation.

PART III: RESULTS

Profile Changes

37. Profiles of the beach showing project performance from its completion in 1982 through May 1984 are presented in Figures 8 and 9. A summary of estimated volume changes derived from these profiles is given in Table 4. Between the as-built (1982) survey and June 1983 survey (approximately 1 year of project operation), most of the profile changes occurred in an offshore direction as material in the construction berm moved downslope as expected. For example, between baseline sta 0+00 and 100+00, the volume of material above the -4 ft elevation decreased by 424,500 cu yd while between the -4 ft and -25 ft depths, the volume of material increased by 394,800 cu yd yielding a net loss for the entire 10,000-ft segment of only 29,700 cu yd. From sta 100+00 to 140+00, a similar adjustment occurred with 366,600 cu yd being removed from above the -4 ft level and 331,600 cu yd accumulating between -4 ft and -25 ft resulting in a net loss of 35,000 cu yd from the northern 4,000 ft of the project. Overall, the net loss of material from the project during the first year was 64,700 cu yd, considerably below the estimated deficit of 160,000 cu yd/year predicted by the feasibility report (O'Brien 1931)*. By the end of the first year, however, practically all of the material placed above -4 ft in front of the seawall from sta 120+00 north had been removed. North of the project limits, between sta 140+00 and 180+00, there was a net buildup of material between August 1982 and June 1983 of 217,000 cu yd.

38. From June 1983 to May 1984 (second year of project operation), losses from the project fill above the -4 ft level increased considerably, with the southern 10,000-ft section losing 64,900 cu yd and the northern 4,000-ft section losing 94,800 cu yd. Unlike the first year, sediment losses also occurred below the -4 ft depth. Over the southern 10,000 ft of the project, losses below -4 ft amounted to 131,900 cu yd, while between sta 100+00 and 140+00, the lower portion of the profile lost 248,100 cu yd. In all, the southern 10,000 ft of the project lost 196,800 cu yd during the second year of project operation, and the northern 4,000 ft lost

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* Op cit.

342,900 cu yd. The total loss from the project during the second year was 539,700 cu yd, and the cumulative loss from the project during the first 2 years was 604,000 cu yd or about 302,000 cu yd/year.

39. Even with the rather substantial sediment losses, as of May 1984 the project remained in excellent condition south of sta 100+00 where a considerable portion of the construction berm was still intact. North of sta 100+00 to 116+40 at the south end of rubble seawall, the berm and dune section had experienced some damage as the erosion had progressed beyond the construction berm into the storm berm portion of the authorized profile. In front of the seawall, the sand level had essentially been reduced to approximately that of the 1981 prefill condition. The 4,000 ft of beach north of the project continued to accrete during the second year, gaining 456,500 cu yd for a total net gain of 673,600 cu yd between August 1982 and May 1984.

Project Volume Changes

40. Part of the erosion from Carolina Beach following the 1982 reconstruction was probably the result of fill material being sorted by waves. Sorting occurs as the waves redistribute the discrete particle sizes in the fill material to their point of equilibrium on the profile. However, some of the material, particularly the finer fraction, may not be stable at any location on the profile and is either swept out of the project area by littoral currents or carried to and distributed over the deeper portions of the beach profile where it cannot be detected by existing survey techniques.

41. In the case of the 1982 fill, a large amount of the finer material appeared to be lost during the filling operation and not as a result of wave sorting. For example, before and after dredging surveys made in the borrow area indicated that 3,662,000 cu yd of fill was dredged, while beach profile surveys taken before and after placement of the fill indicated that only 2,941,000 cu yd were placed on the beach. Excluding any inaccuracies in the survey data, it appears that, for every cubic yard of material that remained on the beach during construction, approximately 1.25 cu yd of material was removed from the borrow area.

42. Granulometric analysis of the borrow material made on samples obtained from borings prior to dredging and auger samples of the in-place fill material indicated that some fines were lost during placement. The analysis

of the in situ or boring samples resulted in a composite mean particle size of 1.72 phi* and a standard deviation of 1.01 phi, whereas the auger samples of the in-place material had a slightly coarser and less well-distributed range of particle sizes with a composite mean of 1.49 phi and a standard deviation of 0.90 phi. The critical ratio (as defined in the Shore Protection Manual** (1984)) between these two composite distributions is 1.27, implying that for every cubic yard of material that remained on the beach during construction, 1.27 cu yd of material was removed from the borrow area. The agreement between the critical ratio and the actual amount of overdredging from the borrow area indicates a loss of a considerable portion of the finer borrow material during placement, as was anticipated.

43. Volume losses from the fill during the first 2 years of project operation, discussed above and shown in Table 4, were determined from surveys of the fill following construction and, therefore, do not include the losses that occurred during placement. Some additional sorting losses may have taken place during the first 2 years of operation; however, these losses could not be determined.

44. The overall performance of the fill during the first year was excellent and appeared to be responding as expected with large quantities of material being displaced seaward from the construction berm. During the second year, much of the material that had moved offshore to between -4 and -25 ft disappeared. Some of this material probably continued to move seaward and was dispersed over the relatively flat bottom seaward of the 25-ft depth. In addition to the losses downslope, large quantities of the fill material were moved to the north and south beyond the project limits by wave-generated longshore currents.

45. The ocean bar channel at Carolina Beach Inlet has, for the past several years, been oriented parallel to the downdrift or south side shoreline as shown in Figure 4. With this bar channel configuration, the rate of sand movement from north to south past the inlet has been greatly enhanced. For example, between 1967 and 1973 during which time the bar channel was oriented primarily perpendicular to the adjacent beaches, the rate of accretion within

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* d(mm) = 2.

** Shore Protection Manual. 1984. 4th ed., 2 vols, US Army Engineer Waterways Experiment Station, Coastal Engineering Research Center, US Government Printing Office, Washington, DC.

this northern beach area was 68,000 cu yd/year (O'Brien 1931).* Between 1982 and 1984 the rate of accumulation was 337,000 cu yd/year. However, not all of this increased rate of accumulation can be attributed to Carolina Beach Inlet, as there has also been an increase in the rate of northward sediment transport off the north end of the Carolina Beach fill.

46. Plan views of the average foreshore position of Carolina Beach before the 1982 fill, immediately following the 1982 fill, and in June 1983 and May 1984 are shown in Figure 10. Also shown in this figure is a hypothetical equilibrium shoreline that would probably form if the rubble-mound seawall at the north end of the project was removed and periodic beach nourishment discontinued. This hypothetical equilibrium shoreline simply connects in the south with shoreline unaffected by the seawall, and in the north with the portion of the beach where inlet effects dominate. Compared to the hypothetical shoreline, the actual beach planform protrudes seaward forming a rather large bulge between sta 70+00 and 150+00, particularly for the shoreline following the placement of the 1982 fill. Between baseline sta 115+00 and 150+00, waves arriving from the southern quadrant would have broken at a much larger angle than normal relative to the post-1982 fill shoreline, while waves originating from the northern quadrant would have smaller than normal breaker angles along this reach. This deviation in wave breaker angles from the normal case would have produced a larger northward littoral transport between sta 115+00 and 150+00 and a reduced southerly rate over this same reach. The postfill shoreline shape would have also caused the net southerly sand transport to be higher than normal between sta 115+00 and 70+00. Some evidence of these altered sand transport rates is available from the volumetric changes that occurred between various profile survey stations on Carolina Beach which are summarized in Table 5. From the as-built condition in 1982 to June 1983, the shoreline between sta 120+00 and 150+00 accreted 139,400 cu yd while the adjacent sections both north and south of this reach eroded. Similarly, the beach between sta 100+00 and 40+00 gained 109,100 cu yd during the same period, again while the adjacent sections eroded. The accretion of material in these isolated zones, which are located near the extremities of the shoreline bulge, indicates that material was transported into these sections faster than it could be carried away. From June 1983 to May 1984, these two accretion zones also began to erode while accretion occured at

* Op cit.

the extreme southern end of the project between sta 10+00 and 0+00 and at the north end of the beach between sta 150+00 and 180+00. The change in the erosion-accretion pattern during the second year of project operation indicates a return to more normal littoral transport as well as the longshore movement of material out of the project area.

47. During construction of the 1982 fill, the volume of material placed on the beach between sta 0+00 and 100+00 exceeded the design volume by 824,000 cu yd, while between sta 100+00 and 140+00 the in-place volume was 97,000 cu yd less than the design volume. Consequently, even with the loss of 226,000 cu yd from sta 0+00 and 100+00 during the first 2 years following project reconstruction, the authorized berm and dune cross section within the 10,000-ft segment remained intact. Losses from this 10,000-ft segment are expected to decrease with time after adjustments from the construction berm take place. Over the northern 4,000 ft of the project, the loss of 378,000 cu yd of fill material during the first 2 years combined with an initial shortfall of 97,000 cu yd during reconstruction produced a total deficit, as of May 1984, of 475,000 cu yd. This deficit resulted in some damage to the berm and dune section between sta 100+00 and 116+40 (south end of the seawall) as erosion progressed into the storm berm portion of the profile and completely removed the protective beach from in front of the seawall.

Hurricane Diana

48. The southeastern coastal area of North Carolina was affected by Hurricane Diana between 10 and 13 September 1984. Hurricane Diana formed off the east coast of Florida on 8 September and moved slowly toward the northeast, paralleling the coast. On 10 September, as Diana approached the North Carolina coast, tides were 1 to 2 ft above normal. Diana was moving toward an apparent landfall near Cape Fear on 11 September; however, the storm turned seaward and moved to a point approximately 50 miles due east of Cape Fear. The storm remained essentially stationary during much of the day on 12 September but by late evening had begun to move back toward land. The eye of Diana made landfall around 0300 on 13 September crossing the coast near Fort Fisher and continuing on a west-southwesterly course across the inland sections of Brunswick County before turning northward and losing strength over the sand-hill section of North Carolina.

49. During Diana's first pass-by on 11 September, tides along the coast were 2 to 3 ft above predicted levels with a maximum surge of 3 ft occurring around 1530 hr. This maximum surge corresponded with the predicted time of low water, so the actual still-water level at this time was only +0.5 ft. The peak water level associated with the first pass-by occurred around 2200 hr on the 11th with a height of +4.6 ft recorded at Carolina Inlet Marina, located directly across the AIWW from Carolina Beach Inlet.

50. Diana finally made landfall during the morning of 13 September. Recorded tide levels at the Carolina Inlet Marina during the hurricane's landfall along with predicted tides for Masonboro Inlet are shown in Figure 11. The Masonboro Inlet predicted tides were used as a basis of comparison since predictions are not available for Carolina Inlet Marina, and the phasing and tide range for Masonboro Inlet and the marina are similar. When Diana made landfall, the predicted astronomical tide was falling and stood at a level of approximately -0.4 ft when the peak surge of 5.5 ft occurred around 0200 hr. Thus, the maximum still-water level recorded at the marina was +5.1 ft. Maximum tides along the open coast were probably similar to this but could have been slightly higher.

51. Following the passage of Hurricane Diana, beach profile surveys of Carolina Beach were made to determine the changes in the shoreline caused by the storm. These surveys were made between 24 and 28 September and covered the profile lying above the -4 ft plane. The prestorm survey for Carolina Beach was made 4 months earlier in May; therefore, the effects of Diana had to be estimated by subtracting the changes that normally would have occurred during the 4-month interval from the changes that were actually measured. Normal changes during the 4-month period were based on the average monthly rate of change measured between June 1983 and May 1984. A typical example of the profile surveys for June 1983, May 1984, and September 1984 measured at sta 40+00 is given in Figure 12.

52. Between sta 0+00 and 100+00, the volume of material on the profile above the -4 ft plane decreased by 222,900 cu yd between May and September 1984. Of this amount, approximately 23,600 cu yd would normally have been lost. Thus, the volume change above the -4 ft plane apparently caused by Diana was 199,200 cu yd. This volume change above the -4 ft depth is equivalent to a 45-ft average retreat of the entire foreshore from +8 to -4 ft .

53. Although poststorm surveys of the offshore section of the profiles

were not made, a considerable portion of the material eroded from the foreshore by Diana was probably displaced seaward to form shore-parallel bars. With the passage of the storm and a return to milder wave conditions, some of this displaced material is expected to work its way back onto the foreshore. Evidence of this poststorm recovery phenomenon was observed from repeat surveys made of profile sta 90+00, 100+00, and 110+00 on 4 October 1984, an example of which is shown for sta 100+00 in Figure 13. At these three profile stations, the foreshore had moved seaward between 5 and 15 ft during the 26 September to 4 October period.

54. Foreshore erosion associated with Hurricane Diana along the northern 4,000 ft of the Carolina Beach project was limited since most of the 1982 fill material placed in front of the seawall had been eroded prior to the storm. Between May 1984 and September 1984, the amount of material removed from the foreshore between sta 100+00 and 140+00 was 49,600 cu yd. Of this amount, 32,600 cu yd was removed from the berm and dune section between sta 100+00 and 116+40, and 17,000 cu yd was lost from in front of the seawall. Based on the average rate of foreshore erosion that occurred between June 1983 and May 1984 along this 4,000-ft segment, normal or nonstorm-related erosion would have displaced about 38,000 cu yd. Therefore only 11,600 cu yd of foreshore erosion can be attributed to Hurricane Diana in this 4,000-ft reach. Poststorm recovery of the beach profile immediately south of the seawall did not occur, as evidenced by a 4 October 1984 survey of sta 115+00 which indicated additional erosion since the September poststorm survey.

Carolina Beach Inlet Sediment Trap

55. Surveys of the sediment trap in Carolina Beach Inlet, created with the removal of 406,000 cu yd of material during the May 1981 emergency beach nourishment operation, showed an accumulation of 270,000 cu yd of sand as of May 1984. This represents an annual accumulation rate of 90,000 cu yd/year.

56. The rate of accumulation during the 36-month period was not constant as shown by the incremental filling rates given in Table 6. During the initial 7-month period from May 1981 to September 1981, the average rate of sediment accumulation was 13,700 cu yd/month, while over the next 29-month period, the rate decreased and remained fairly constant, averaging about 6,000 cu yd/month. A scour, and fill map of the deposition basin, which covers

the 3-year period from May 1981 to May 1984, is given in Figure 14. Of the 270,000 cu yd total accumulation, 223,000 cu yd, or 77 percent, deposited in the seawardmost portion of the trap, which is designated as "Fill Area No. 1" in Figure 14. The middle portion of the trap, accumulated 65,500 cu yd of new sand in "Fill Area No. 2" but also lost 15,500 cu yd to natural scour resulting in a net accumulation of 50,000 cu yd. The landward end of the trap, which extends about 500 ft seaward of the AIWW, gained 17,800 cu yd of new material. However, the adjacent areas north and south of this section of the trap lost a combined total of 20,800 cu yd to scour, yielding a net loss of 3,000 cu yd of sediment from the entire landwardmost area. Failure of the middle and landward ends of the trap to retain substantial quantities of sediment was due to the concentration of tidal flow through these areas which, in essence, presently constitute the inlet gorge. Overall, the trap has functioned well, but the average annual accumulation of 90,000 cu yd is below that needed to keep pace with the erosion losses from the Carolina Beach project.

57. Since the seaward portion of the sediment trap was rather efficient in trapping material whereas the middle and landward portions were not, the sediment trap was repositioned seaward during the 1985 renourishment of Carolina Beach. The new location, shown in Figure 4, was outside the area of concentrated tidal currents that prevented material from depositing in the original trap.

Tidal Current Measurement

58. A summary of the tidal current measurements made in Carolina Beach Inlet is given in Table 7. These measurements were made in the sediment trap area along a range located approximately 700 ft seaward of the AIWW. These current and discharge measurements indicate that the total volume of water flowing through Carolina Beach Inlet, the tidal prism, did not change as a result of the dredging of the sediment trap; however, discharge velocities did decrease. Discharge velocities have remained rather low in this section of the trap due to its failure to accumulate any substantial quantities of material.

59. Based on a September 1981 hydrographic survey, the minimum cross-sectional flow area in Carolina Beach, which was measured seaward of the dredged sediment trap, was 7,050 sq ft. The relationship between an inlet's

cross-sectional area and its tidal prism for uncontrolled inlets on the Atlantic Coast is given by Jarrett (1976)* as the following:

$$A = 5.37 \times 10^{-6} P^{1.07}$$

where

A = cross-sectional flow area measured at mean sea level, sq ft

P = tidal prism of the inlet during spring tide conditions, cu ft

Based on this relationship and the minimum flow area of 7,050 sq ft measured in September 1981, Carolina Beach Inlet should have a spring tidal prism of 3.32×10^8 cu ft. Of the four discharge measurements listed in Table 7, only the June 1981 observations were made during approximate spring tide conditions. The April 1981 and September 1982 measurements were made during periods in which the predicted ocean tide range was slightly less than the mean range, whereas the December 1981 measurements were made during a neap tide. In any event, there is good agreement between the measured flood-tidal prism for Carolina Beach Inlet and that predicted by Jarrett's relationship.

Material Size Characteristics

60. Size characteristics of the material that accumulated in the sediment trap were determined from samples taken from vibracores 1, 2, and 4 through 7 located in the sediment trap (Figure 4). The composite characteristics of this deposited material and the characteristics of the beach material in 1980, the 1981 emergency fill material, the 1982 renourishment material, and the ocean bar samples at Carolina Beach Inlet are given in Table 8.

61. There is no true native beach material at Carolina Beach due to previous beach fills; however, the 1980 beach profile samples can be assumed to be representative of native sand since the material had been in place for approximately 9 years prior to sampling. Based on this assumption, material deposited in the Carolina Beach Inlet sediment trap is coarser than the beach material and has a slightly wider range of particle sizes. The deposited material is also similar to the material placed on Carolina Beach in 1981 and 1982. If used for beach nourishment, the deposited material would have an overfill factor, as defined in the Shore Protection Manual (1984)* of approximately 1.0.

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* Op cit.

PART IV: CONCLUSIONS

62. The Carolina project performed generally as expected but experienced slightly higher volume losses than originally anticipated. Until the material in the construction berm along the southern 10,000 ft of the project moves to the lower portion of the active profile, volume losses along this segment will probably continue to be high. Eventually, the southern 10,000-ft segment is expected to attain some degree of stability. Along the northern 4,000 ft, the sediment deficit caused by Carolina Beach Inlet remains a problem and will require a continuous renourishment program with materials obtained from the Carolina Beach Inlet sediment trap.

63. The sediment trap in Carolina Beach Inlet functioned fairly well but was located too close to the main flow through the inlet to be completely effective. Relocation of the sediment trap seaward and away from the main flow should greatly enhance its overall sand trapping ability. Dredging of the channel through the ebb tide delta eliminated the opportunity to evaluate the trap's effect on the delta and ebb tide channel.

PART V: RECOMMENDATIONS

64. In computing the volume of material required to construct a beach fill having a certain width, the designer must assume that the improved beach profile will parallel the existing beach profile down to some depth of closure. For example, at Carolina Beach, profile slopes seaward of the 25-ft depth are relatively flat and generally outside the normal influence of littoral forces. Therefore, in this instance, design volumes were computed assuming that the improved beach profile would parallel the existing bottom out to -25 ft.

65. Once the design volume is determined, the only practical way to construct the fill is to place the required quantity on the beach in the form of a sacrificial construction berm. The crest elevation of the construction berm should be equal to the natural berm elevation in the area. The width of the construction berm will depend on the slopes that the material assumes during placement and the volume of material to be placed. Since this slope is not generally known beforehand, surveys should be conducted during placement to ensure that the correct volume of material is distributed along the beach. Once in place, the construction berm material will be displaced to the deeper portions of the active profile by wave action.

66. Beach fills should be designed with adequate transitions from the artificial beach back to the natural beach. If the transition is too sharp, material will be eroded from the ends of the fill at a rapid rate and could be transported out of the project area.

67. Sediment traps in tidal inlets should be located in areas removed from the concentrated tidal flows. For example, an ideal location for a sediment trap would be in the area of an existing interior shoal that is fed with littoral material moving off the inlet shoulders. In the case of Carolina Beach Inlet, much of the trap was located in the area of concentrated tidal flows and, as a result, the trap only filled to about 66 percent of its dredged capacity. The trap should also be dredged as deep as possible, but not deep enough to create problems with sloughing of the adjacent shorelines into the trap.

Table 1

Monitoring Completed Coastal Projects Program

Areas of Interest

Shoreline and nearshore current response to coastal structures.
Wave transmission by overtopping.
Prediction of the controlling cross section at inlet navigation channels.
Wave attenuation by breakwaters (submerged and floating).
Bypassing at jettied and unjettied inlets.
Wave refraction and steepening by currents.
Beach fill project monitoring.
Stability of rubble structures--investigations to determine causes of failure.
Comparison of preconstruction and postconstruction sediment budgets.
Wave and current effects on navigation.
Dynamics of floating structures.
Wave reflection.
Effects of construction techniques on scour and deposition near coastal structures.
Diffraction around prototype structures.
Wave runup on structures.
Onshore/offshore sediment movement near coastal structures.
Harbor oscillations.
Wave transmission through structures.
Material life cycle.
Ice effects on structures and beaches.
Model study verification.
Wave translation.
Construction methods.

Table 2

Beach Onshore-Offshore Profile Stations

Station	Survey-Type
-20+00	Onshore-offshore
-10+00	Onshore
0+00	Onshore
10+00	Onshore-offshore
20+00	Onshore
30+00	Onshore
40+00	Onshore-offshore
50+00	Onshore
60+00	Onshore
70+00	Onshore-offshore
80+00	Onshore
90+00	Onshore
100+00	Onshore
110+00	Onshore-offshore
115+00	Onshore
120+00	Onshore-offshore
125+00	Onshore
130+00	Onshore-offshore
135+00	Onshore
140+00	Onshore-offshore
145+00	Onshore
150+00	Onshore-offshore
155+00	Onshore
160+00	Onshore-offshore
170+00	Onshore-offshore
180+00	Onshore-offshore
190+00	Onshore-offshore
200+00	Onshore-offshore

Table 3

Beach Volume Changes

Date of Survey	Stations Surveyed	Type of Survey
Aug-Sep 1981	-20+00 to 200+00	Onshore-offshore
Dec 1981-Jul 1982	0+00 to 200+00	Prefill and postfill onshore-offshore by contractor
Aug 1983	-20+00 to 200+00	Onshore-offshore
May 1984	-200+00 to 200+00	Onshore-offshore
Sep 1984	-20+00 to 200+00	Onshore-post Hurricane Diana

Table 4

Beach Volume Changes

1982-1984

	Survey Periods*		
Shoreline Segment	As-Built 1982 to June 1983 cu yd	June 1983 to May 1984 cu yd	As-Built 1982 to May 1984 cu yd
Sta 0+00-100+00			
Profile above -4 ft	-424,500	-64,900	-489,400
Profile below -4 ft	+394,800	-131,900	+262,900
Total profile**	-29,700	-196,800	-226,500
Sta 100+00-140+00			
Profile above -4 ft	-366,600	-94,800	-461,400
Profile below -4 ft	+331,600	-248,100	+83,500
Total profile**	-35,000	-342,900	-377,900
Sta 140+00-180+00			
Profile above -4 ft	+38,500	+26,200	+64,700
Profile below -4 ft	+178,600	+430,300	+608,900
Total profile**	+217,100	+456,500	+673,600

* Postive signs indicate accretion during survey period, and negative signs indicate erosion.

** Total profile denotes out to a depth of -25 ft.

Table 5
Station by Station Volume Changes, cu yd
1982-1984

Station	As-Built 1982 to June 1983	June 1983 to May 1984	As-Built 1982 to May 1984
	Survey Periods*		
0+00			
	-27,600	+3,100	-24,500
10+00			
	-111,300	-33,500	-144,800
40+00			
	+89,800	-52,000	+37,800
70+00			
	-19,300	-114,400	-95,100
100+00			
	-68,700	-34,600	-103,300
110+00			
	-19,900	-88,900	-108,800
120+00			
	+300	-108,500	-108,200
130+00			
	+53,300	-110,900	-57,600
140+00			
	+85,800	-18,800	+67,000
150+00			
	-2,600	+141,200	+138,600
160+00			
	-39,500	+225,300	+185,800
170+00			
	+173,300	+108,700	+282,000
180+00			

* Positive signs indicate accretion during survey period and negative signs indicate erosion over the entire profile out to a depth of -25 ft.

Table 6

Volume Changes-Sediment Trap

Time Period	Months	Volume Change cu yd	Cumulative Volume Change cu yd	Rate of Volume Change cu yd/month
May 81-Sep 81	4	+53,600	+53,600	+13,400
Sep 81-Dec 81	3	+42,100	+95,700	+14,000
Dec 81-Sep 82	9	+50,200	+145,900	+5,600
Sep 82-Jul 83	10	+67,200	+213,100	+6,700
Jul 83-May 84	10	+56,900	+270,000	+5,700

Table 7

Inlet Tidal Current and Discharge Measurement

Date	Tide Range* ft	Flow Cross-Sectional Area sq ft	Tidal Prism** cu ft Flood	Tidal Prism** cu ft Ebb	Average Maximum Velocities fps Flood	Average Maximum Velocities fps Ebb
22 Apr 81	3.21	8,706	3.21×10^8	3.01×10^8	2.38	2.47
11 Jun 81	3.77	13,504	3.47×10^8	2.36×10^8	1.47	1.29
20 Dec 81	2.51	12,544	1.21×10^8†	2.13×10^8	0.78	1.04
8 Sep 82	3.5††	12,803	3.04×10^8	2.26×10^8	1.55	1.40

* Tide range measured at Carolina Inlet Marina.

** Discharge measurements made in trap area.

† Relatively small flood-tidal prism apparently due to high water on this date being about 1 ft lower than high water on the other dates.

†† Marina gage out of order, tide range estimated from ocean tide range measured at Center Fishing Pier.

Table 8

Composite Size Characteristics of Sand Samples

Description of Samples	Mean, phi* Units	Standard Deviations, phi* Units
Material deposited in sediment trap	1.79	1.24
1980 beach profile material	2.10	1.12
1981 emergency fill material	1.42	0.88
1982 upland borrow area material		
From core borings	1.72	1.01
From in-place samples	1.49	0.09
Ocean bar at Carolina Beach Inlet	0.67	0.70

* d(mm) = 2.

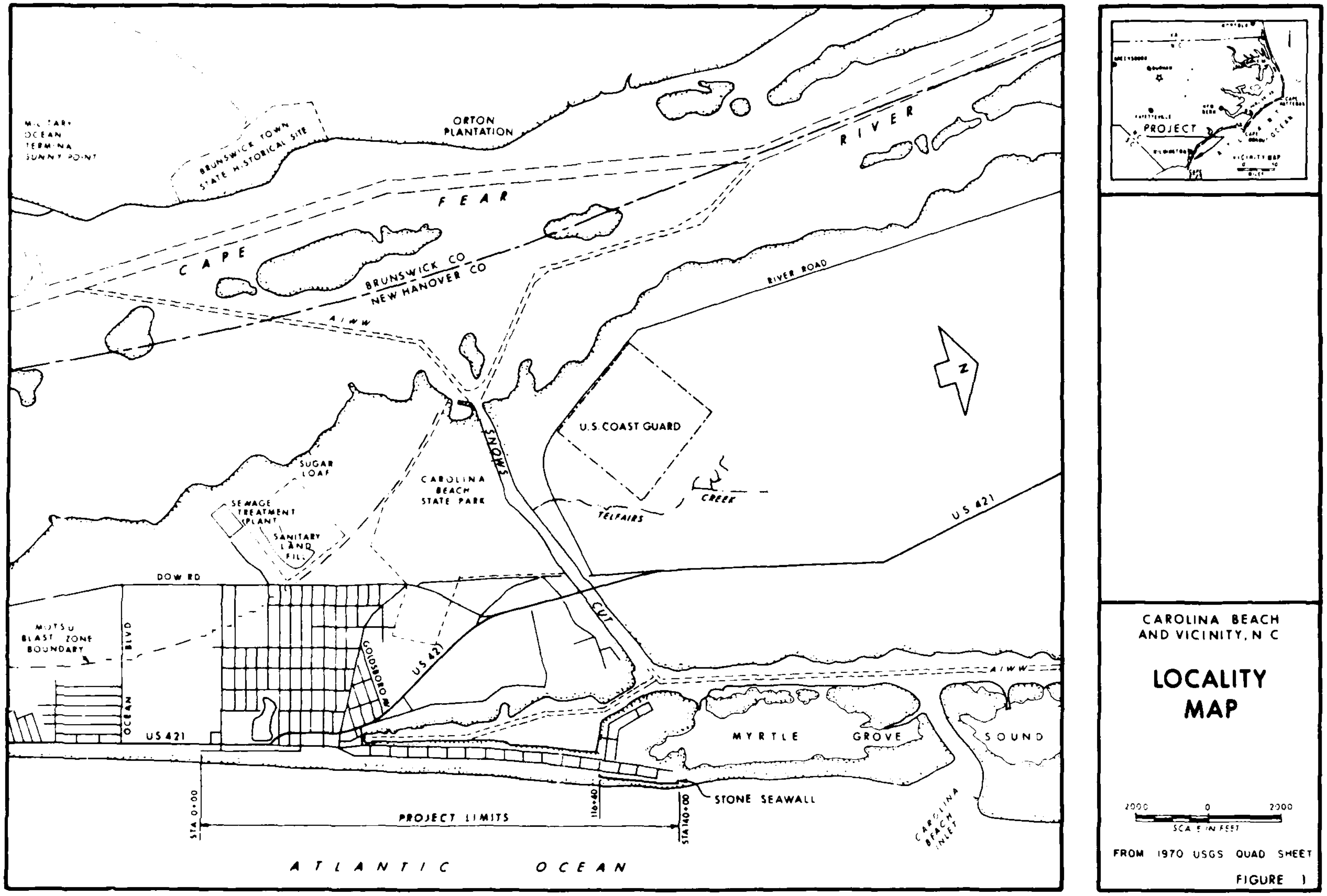

Figure 1. Location map of Carolina Beach and vinicity

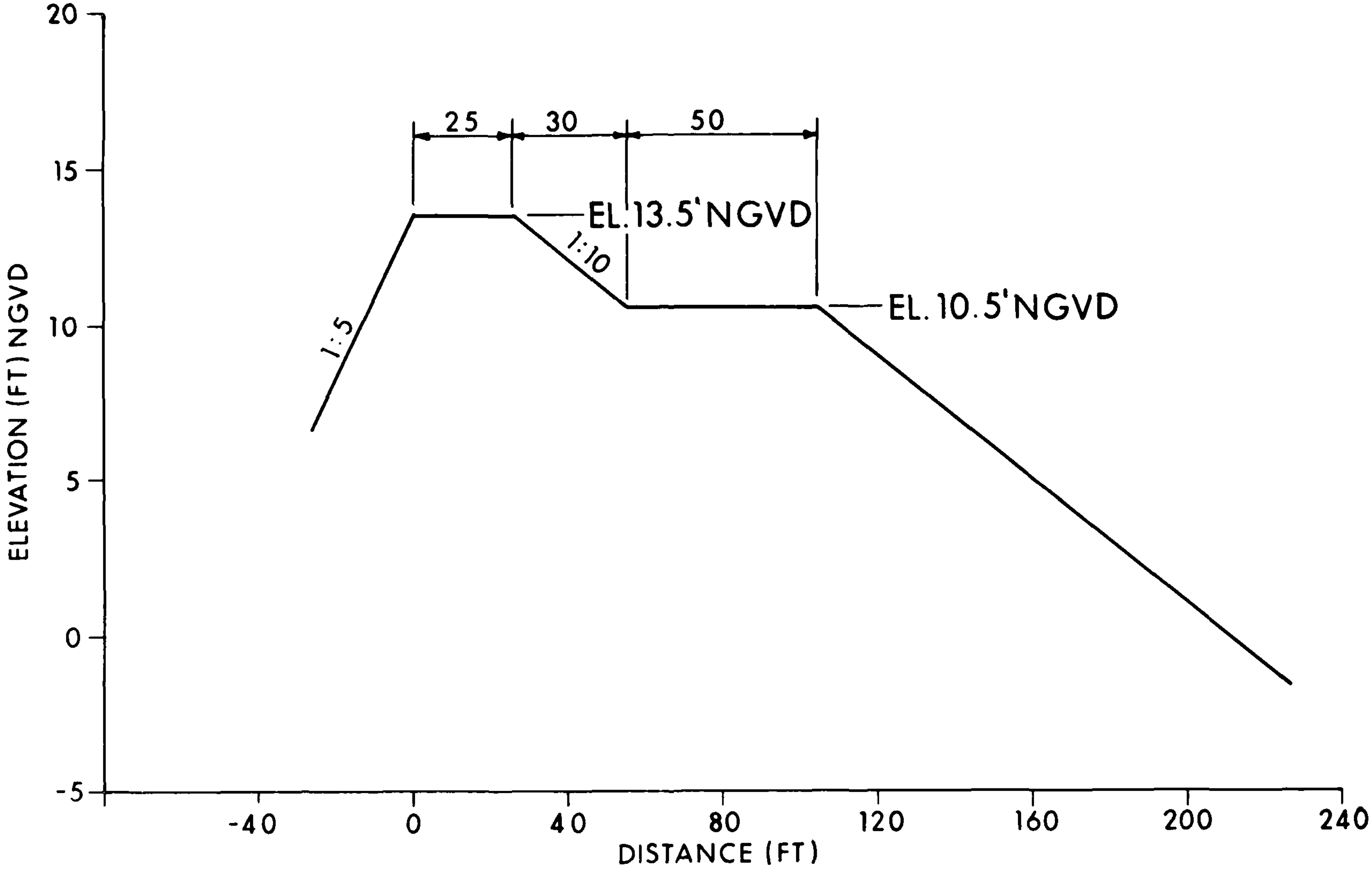

Figure 2. Authorized cross section of the Carolina Beach Hurricane and shore protection project

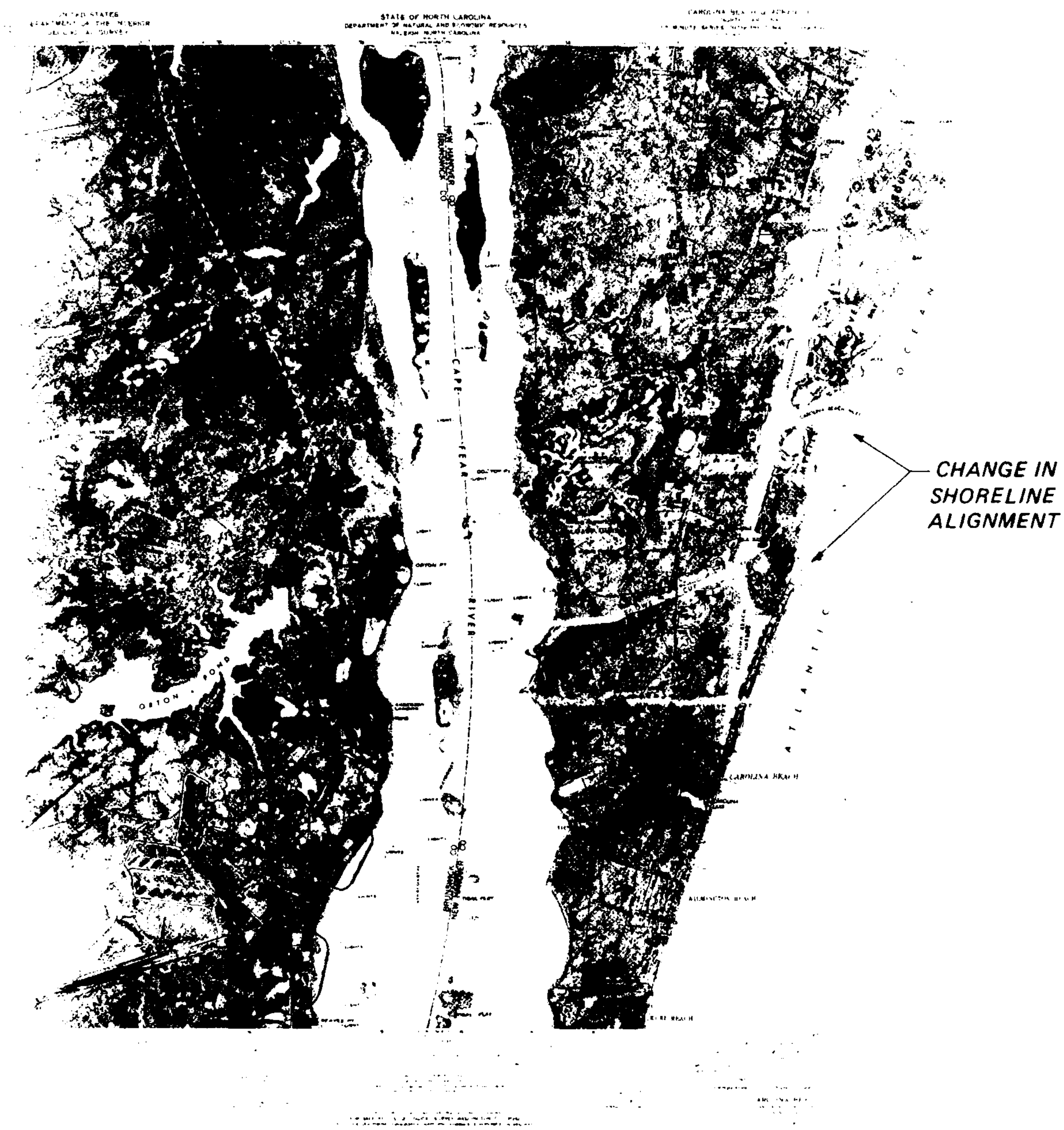

Figure 3. Shoreline alignment change

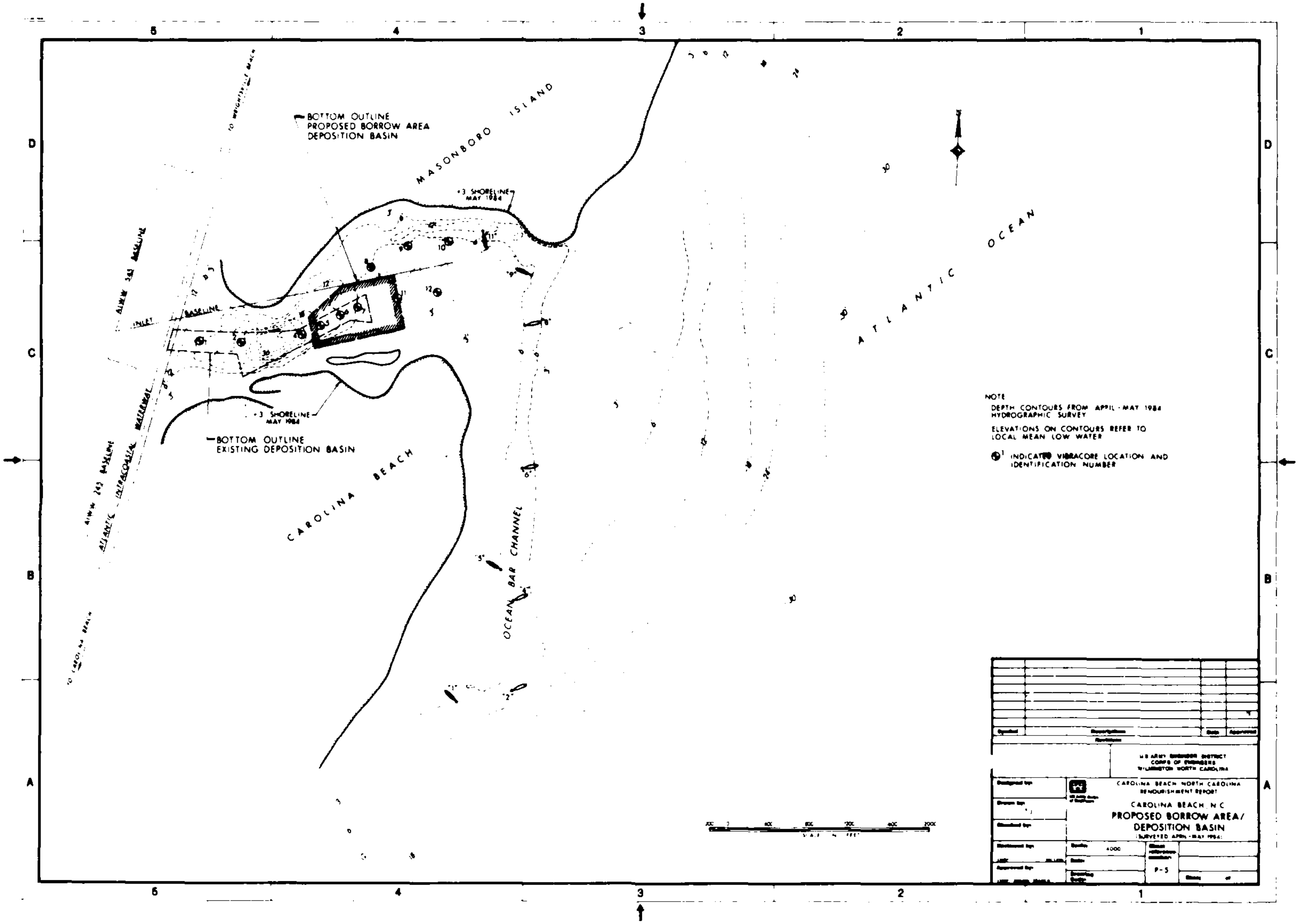

Figure 4. Borrow area

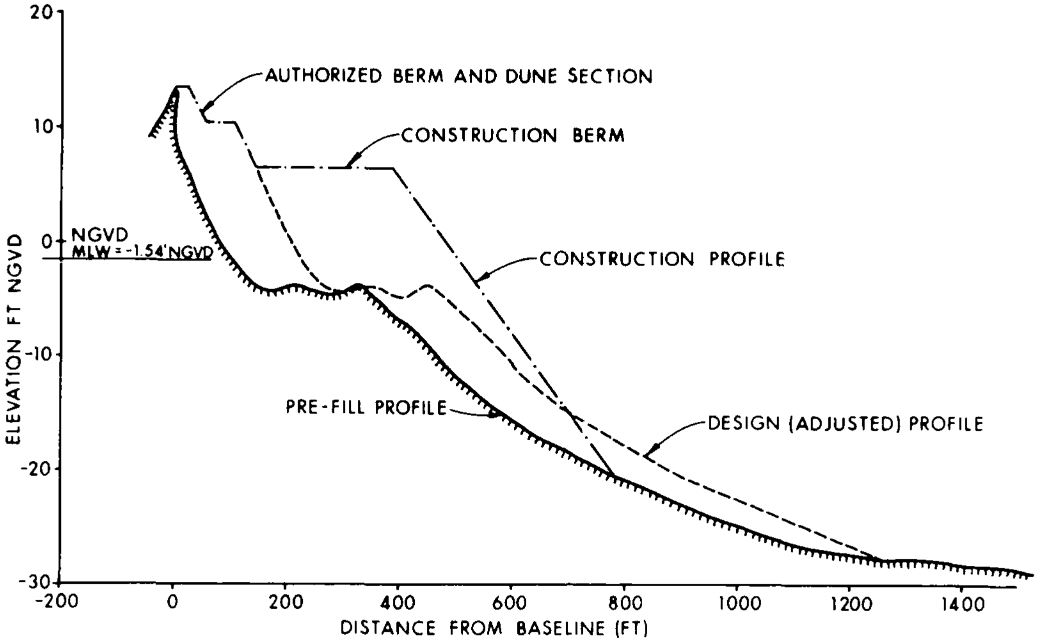

Figure 5. Design and construction profiles, berm and dune beach-fill section

	FY 81		FY 82				FY 83				FY 84			
	3rd QTR	4th QTR	1st QTR	2nd QTR	3rd QTR	4th QTR	1st QTR	2nd QTR	3rd QTR	4th QTR	1st QTR	2nd QTR	3rd QTR	4th QTR
TRAP AND INLET SURVEYS	●		●		●		●		●					
TRAP SURVEYS	■			●		●		●			●			
TIDAL CURRENT MEASURE	● ●			●		●		●						
ONSHORE-OFFSHORE PROFILES	■ ■			●		●		●			●			
ONSHORE PROFILES		●			●		●		●				●	
AERIAL PHOTOS	● ●			●		●		●			●			
GROUND PHOTOS	● ●			●		●		●			●		●	
SEDIMENT SAMPLES	■ ■			●		●					●			
TIDE GAGE	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬
WAVE GAGE	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬
WAVE DIRECTION OBSERVATIONS (DAILY)	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -

Figure 6. Original schedule of activities monitoring plan for Carolina Beach

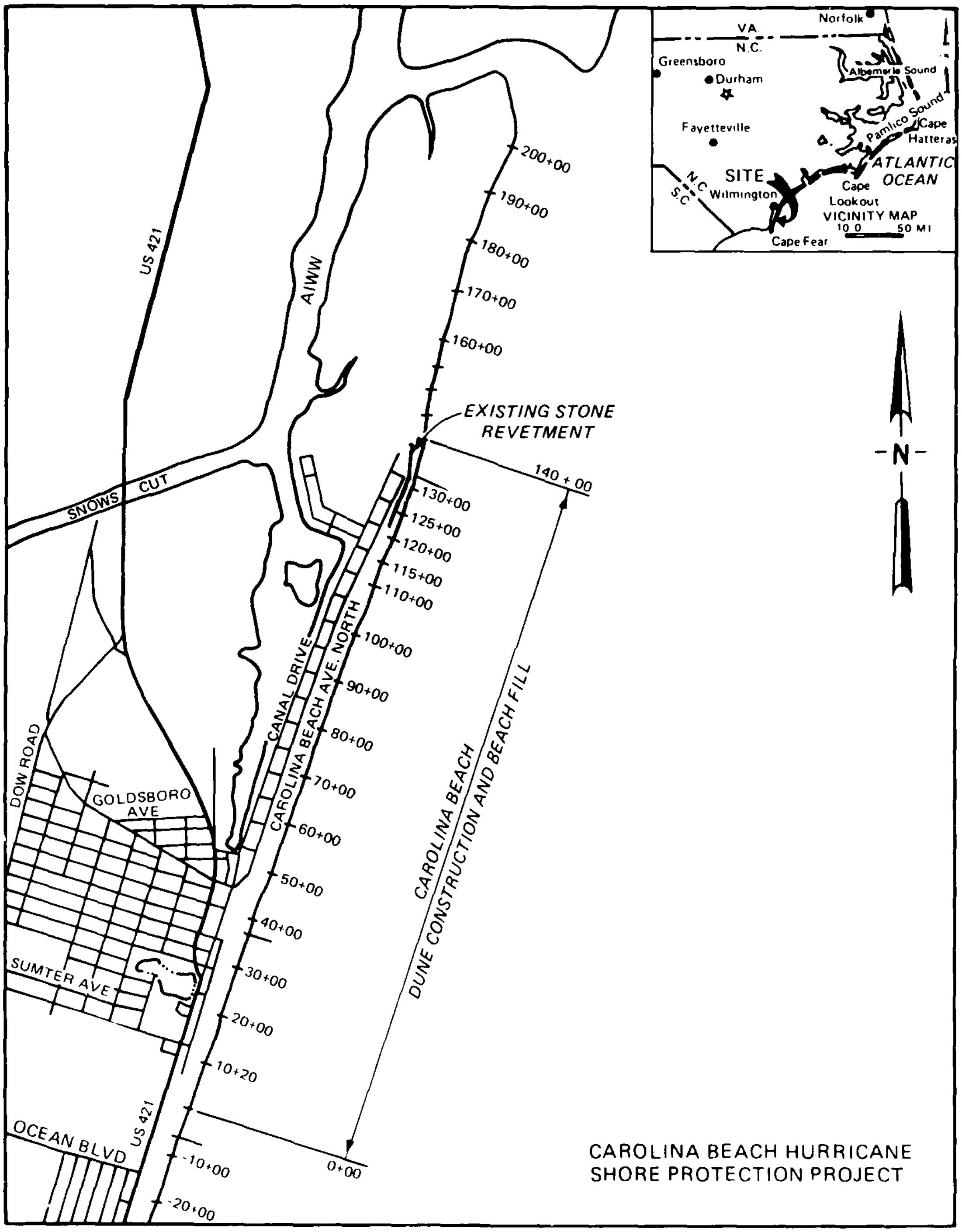

Figure 7. Profile stations

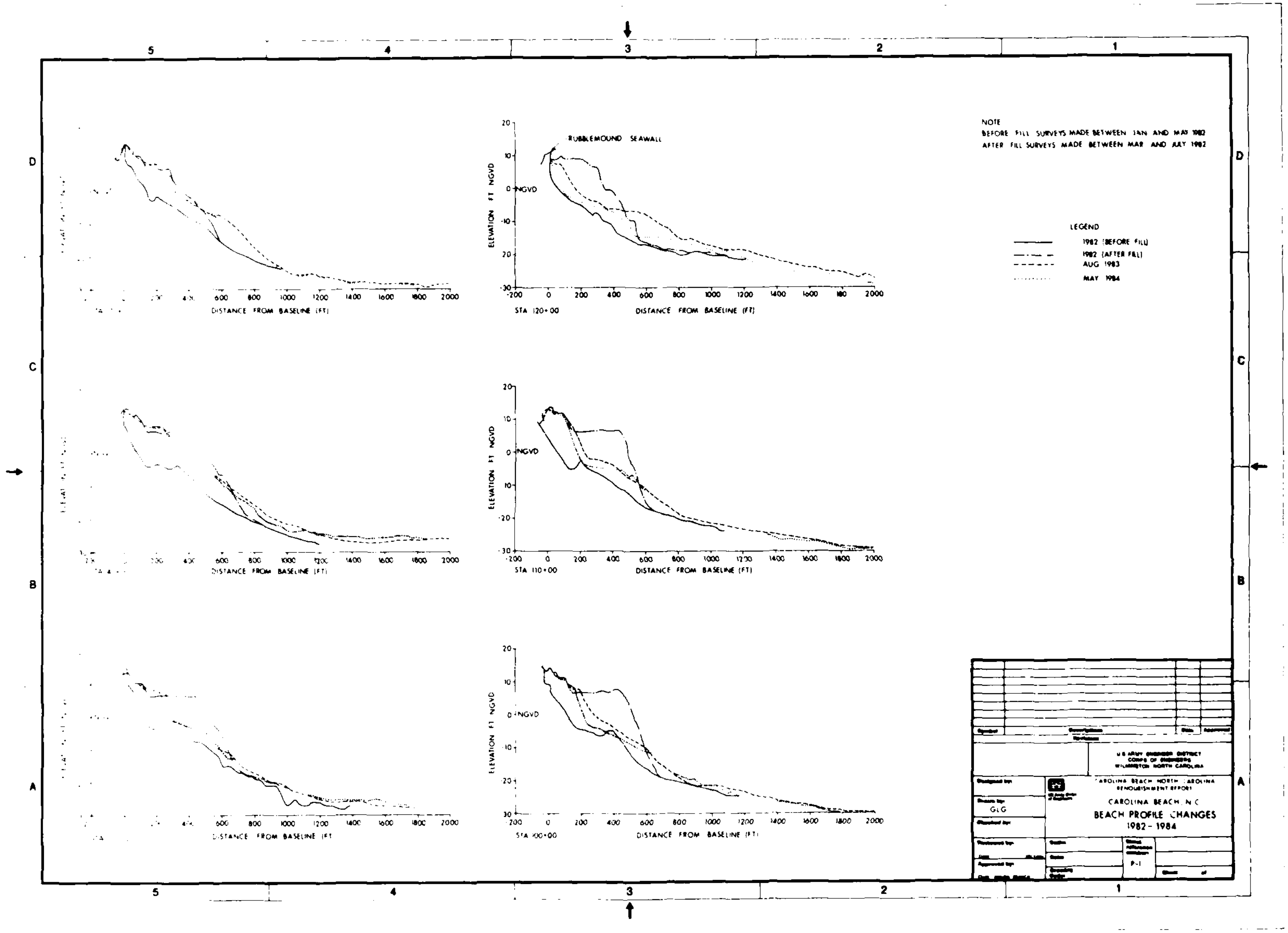

Figure 8. Profile changes, sta 10+00 to 120+00

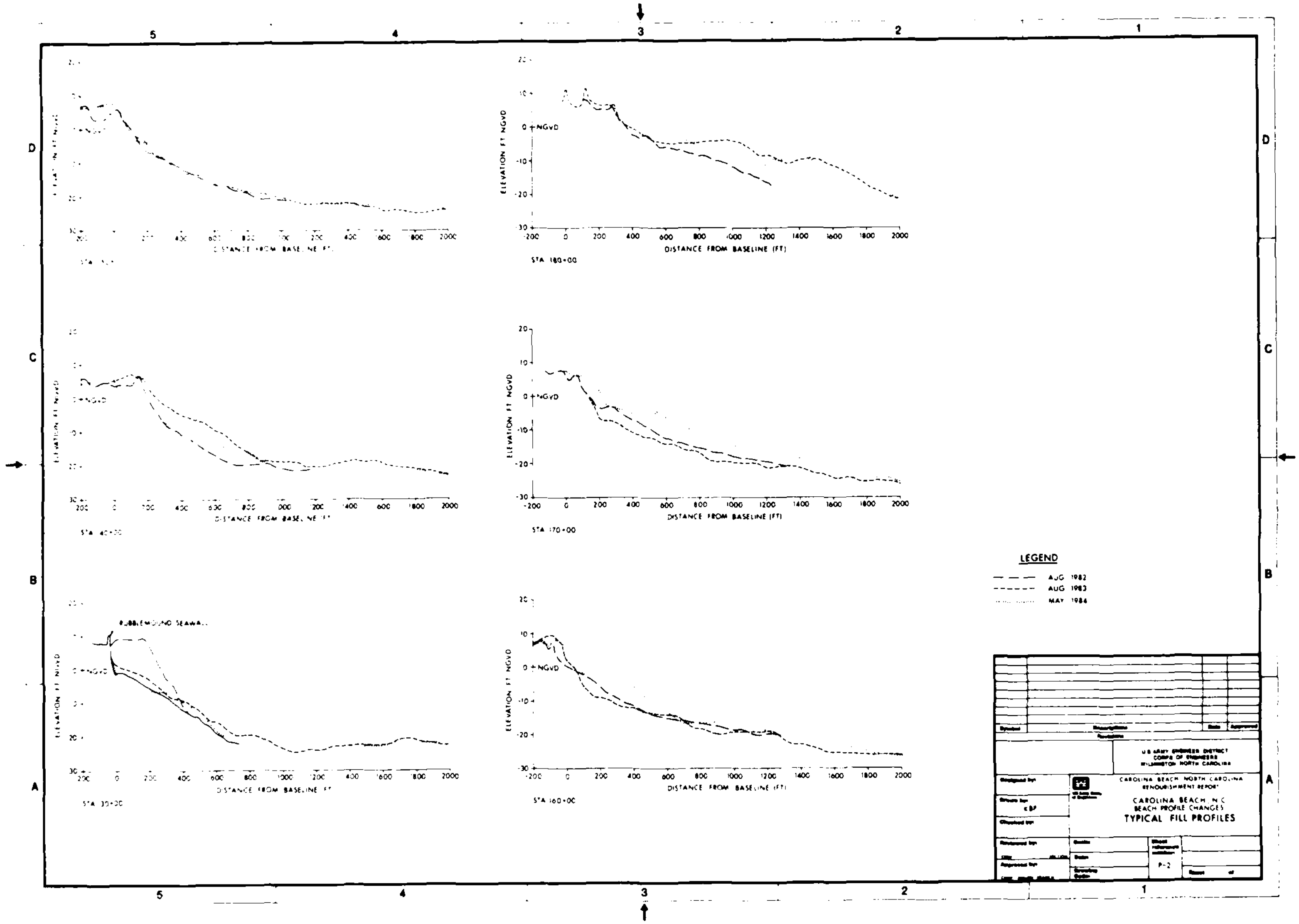

Figure 9. Profile changes, sta 130+00 to 180+00

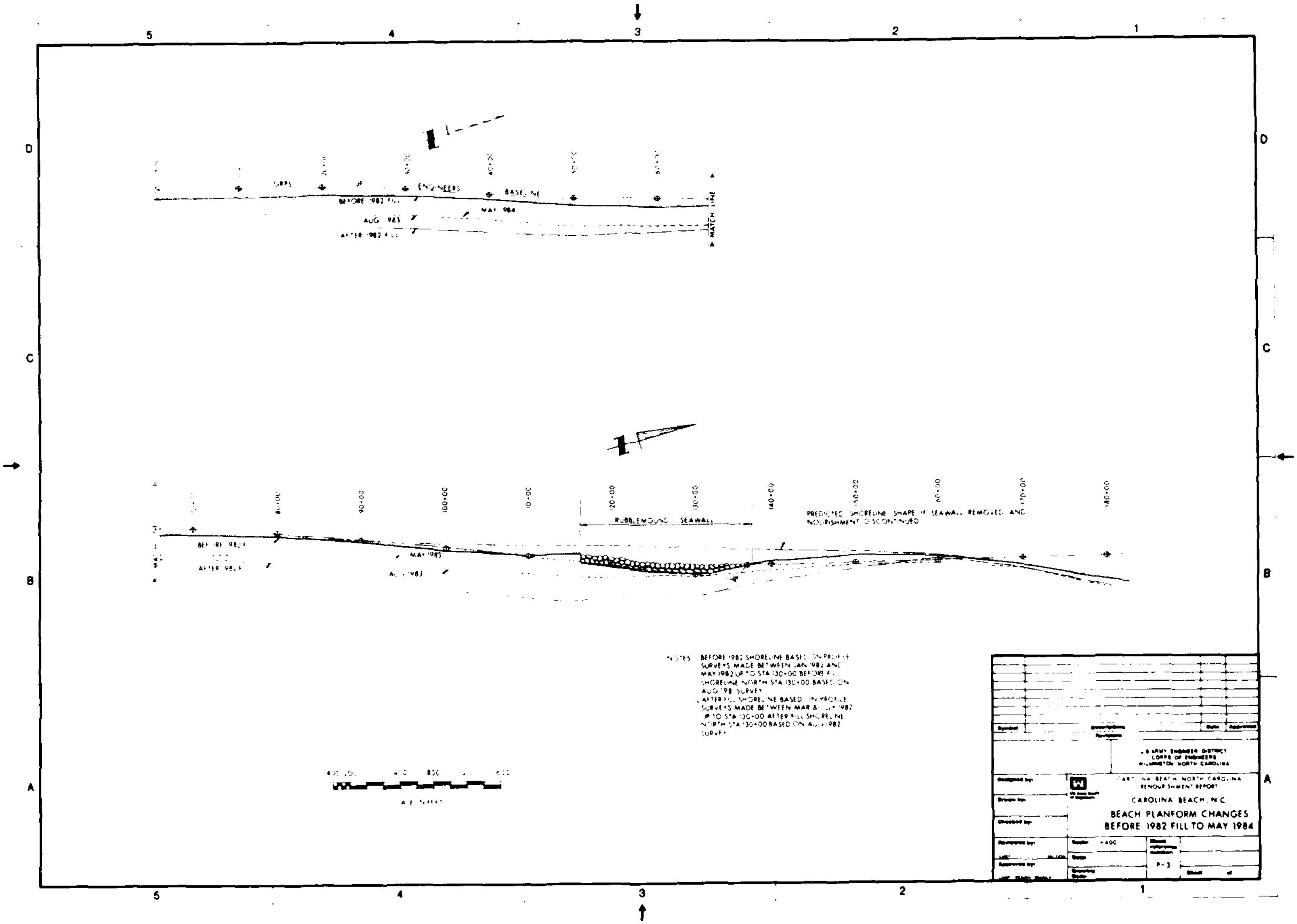

Figure 10. Shoreline positions

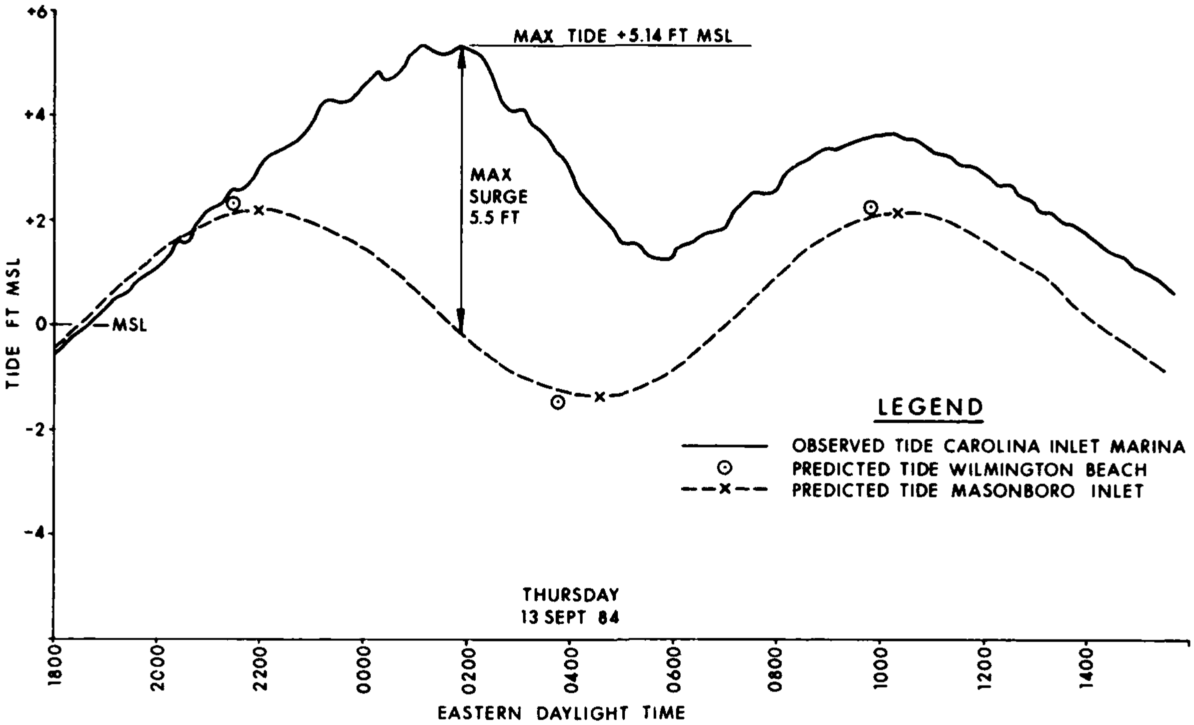

Figure 11. Observed versus predicted tides during Hurricane Diana landfall

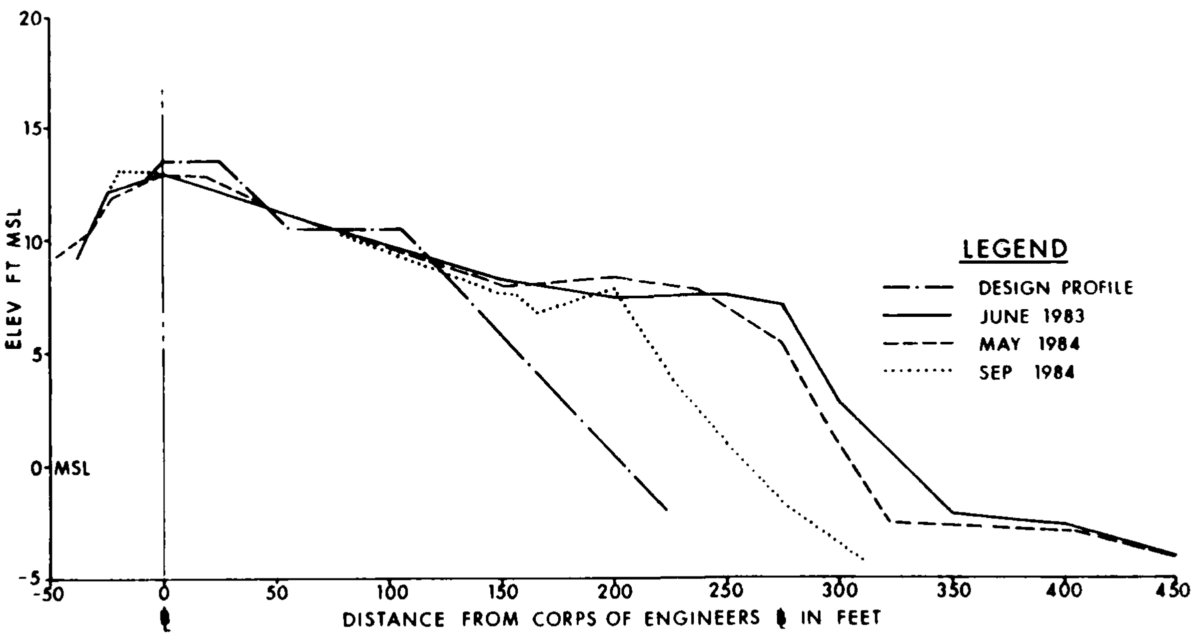

Figure 12. Profile comparison, sta 40+00 Carolina Beach

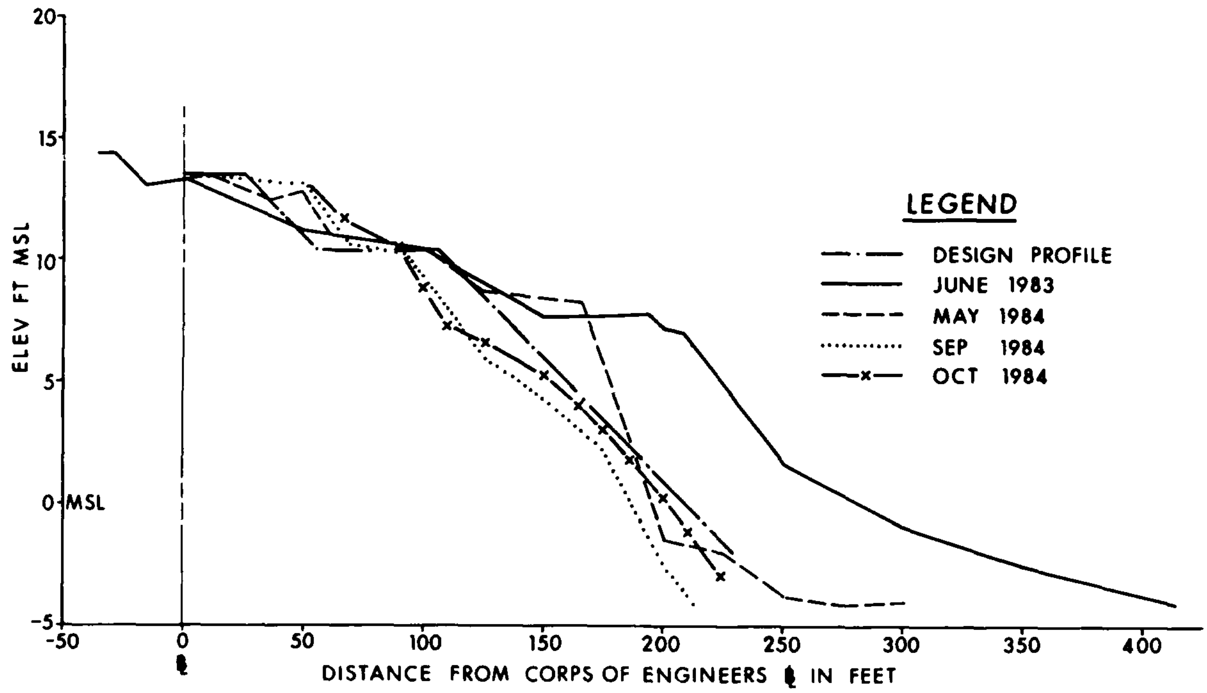

Figure 13. Profile comparison, sta 100+00 Carolina Beach

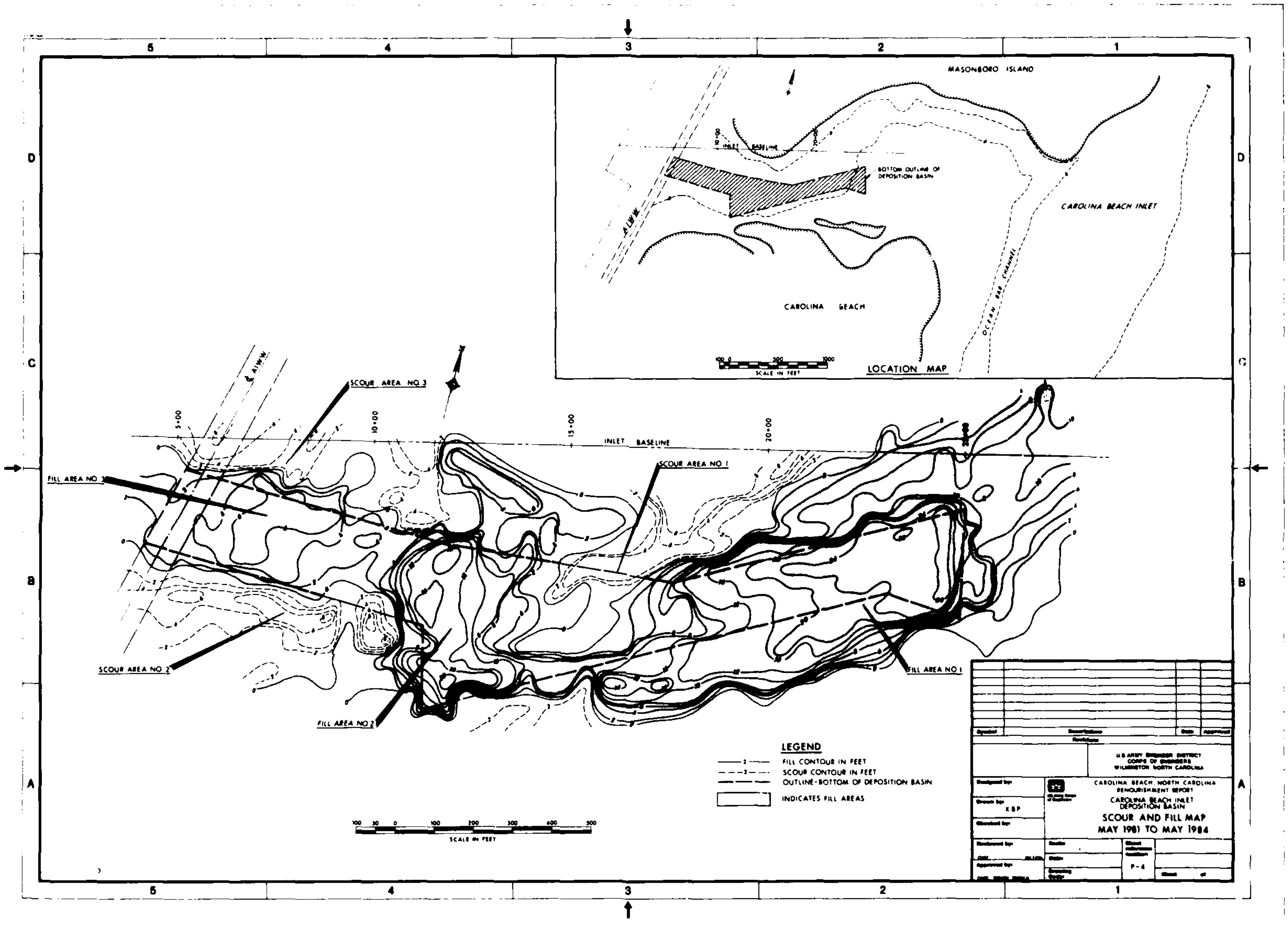

Figure 14. Deposition basin scour and fill

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